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DEPARTMENT OF DEFENSE

DEFENSE LOGISTICS AGENCY

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Prototype Expert System for Hazardous Material Identification and Classification

Operations Research and Economic Analysis Office

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DLA-LO

FOREWORD

The emerging technology of Artificial Intelligence/Expert Systems (AI/ES) offers the potential to automate tasks which now require human judgement, experience and intuition. Because implementing this technology can be expensive, especially if done inappropriately, the DLA Operations Research and Economic Analysis Management Support Office (DORO) has chosen to develop prototype systems in order to determine the suitability of AI/ES solutions to specific logistics problems. This report documents the development of a prototype expert system designed to demonstrate the feasibility of using AI to support the implementation of a new hazardous material classification system.

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EXECUTIVE SUMMARY

The Depot Operations Division, Directorate of Supply Operations (DLA-OW) is implementing a new hazardous material classification system consisting of 55 Hazardous Characteristic Codes (HCC). The HCC will provide critical information needed to effectively manage, store and ship hazardous materials.

With implementation of the new DLA Warehousing and Shipping Procedures (DWASP), depot receiving personnel will be required to assign the HCC if it is missing from pertinent documents. Because the HCC must be assigned quickly and accurately, an expert system approach appeared to offer the best means of assisting depot personnel in performing this task.

The purpose of this project was to determine if an expert system approach to assigning HCCs is feasible and advisable. Accordingly, a prototype expert system was developed which has the capability of assigning ten HCCs to a specific category of hazardous materials. Subject to the results of field testing at DLA depots, the prototype system has demonstrated that it is feasible and advisable to develop an operational expert system for the assignment of hazard codes.

I. INTRODUCTION. The emerging technology of Artificial Intelligence/ Expert Systems (AI/ES) offers the potential to automate tasks which now require human judgement, experience and intuition. Because of the heavy investment of personnel, computer and other resources that can be involved, AI/ES applications should be developed and implemented only where the technology is shown to be appropriate, where there is an acceptable level of risk, and where the benefits outweigh the costs of development. One means of achieving that goal is through the development of prototype systems. Accordingly, the DLA Operations Research and Economic Analysis Management Support Office (DORO) has developed a prototype Hazardous Material Analysis and Coding System (HAZMACS).

A. Background

The Depot Operations Division, Directorate of Supply Operations (DLA-OW) is implementing a new hazardous material classification system consisting of 55 Hazardous Characteristic Codes (HCCs). The HCC will provide critical information needed to effectively manage, store and ship hazardous materials.

Under current DLA methods, a hazardous storage compatibility code is assigned to appropriate items by trained chemists and chemical engineers employed at the DoD Hazardous Materials Data Bank Branch located at the Defense General Supply Center (DGSC-SLM). This information is maintained by DGSC-SLM in the DoD Hazardous Materials Information System (HMIS).

With implementation of the new DLA Warehousing and Shipping Procedures (DWASP), a depot storage location cannot be assigned unless the HCC is known. This will require that depot receiving personnel assign HCCs if they are missing from pertinent documents. Because of the wide range of hazardous materials received and the variety of shipping and handling documentation which may accompany these receipts, it may be very difficult for depot personnel to properly classify this material without some kind of ongoing technical support. Because a high degree of accuracy is essential to selecting the correct storage location and determining appropriate handling procedures, an expert system approach appears to offer the best means for providing this technical support to depot personnel in a consistent and coherent manner.

B. Purpose

The purpose of this project was to determine if an ES approach to assigning Hazardous Characteristic Codes is feasible and advisable. The feasibility of such an approach will depend largely on the characteristics of the problem of assigning HCCs and whether those characteristics lend themselves to an ES solution. Typically, ES solutions are desirable in situations where conventional programming techniques don't solve the problem effectively and the solution involves the use of logical reasoning (i.e., nonnumeric). In this case it was decided that an ES solution would be expected to: (1) accurately and quickly assign HCCs, (2) require minimum interaction by the user, and (3) provide the flexibility to either identify a general hazardous category for storage purposes or determine the specific HCC for entry into the HMIS.

The advisability of an ES approach pertains more to the environment within which the ES application would be developed and implemented and the degree to which that environment will contribute to success. Under normal circumstances, good indicators of successful ES applications include such factors as the availability and accessibility of human "experts," how receptive the end-users are to an ES application, and whether the benefits of an ES solution outweigh the costs of its development.

C. Objective. Our objective in this initial effort was to develop a prototype expert system which accurately and quickly assigns Hazardous Characteristic Codes to a specific category of hazardous materials received and stored in DLA depots. Subsequently, as a follow-on effort, the prototype system could be expanded to an operational ES application if it is demonstrated that such a system is feasible and advisable.

D. Scope. Based on discussions with DLA-OW, DGSC-SLM, and the Technical and Logistics Data Division, Directorate of Technical and Logistics Services (DLA-SC), it was decided to confine the scope of the prototype system to classification of corrosive materials. Specifically, it was agreed that the system would be capable of assigning the following five hazard codes:

HCC		Hazard Group
C1	-	Corrosive, DOT, Acid
C2	-	Corrosive, DOT, Alkali
C3	-	Acid, Low Risk
C4	-	Alkali, Low Risk
J6	-	Miscellaneous Corrosive Material

Subsequently, it was agreed that the prototype should demonstrate a capability for classification of multiple hazards. Accordingly, the following two codes were added:

D4	-	Oxidizer and Corrosive
F6	-	Flammable Liquid and Corrosive

With the knowledge base additions required to assign the F6 - Flammable Liquid and Corrosive code, it became obvious that the capability to assign certain related codes could be incorporated in the prototype with relatively little additional effort. Therefore, the following three codes were added:

F7	-	Flammable Solid
J1	-	Miscellaneous Flammable Liquid
J2	-	Miscellaneous Flammable Solid

Thus, the prototype expert system has the capability to assign a total of ten HCCs.

II. CONCLUSIONS

A. The HAZMACS prototype demonstrates that an operational ES for assignment of Hazardous Characteristic Codes is feasible for the following reasons:

- HAZMACS has the capability to accurately and quickly assign ten HCCs.

- Through the use of menus and "yes or no" options, HAZMACS demonstrates that necessary information can be obtained with minimum interaction by the user.

- HAZMACS demonstrates that significant quality control can be incorporated within an expert system in terms of consistency and completeness of input information.

B. The potential for successful development of an operational ES is enhanced by the following factors:

- HAZMACS has demonstrated that an expert system can be developed without placing inordinate demands on "human experts" by employing a process of testing and validating a series of interim systems.

- It is believed that the benefits pertaining to safety, reduced re-warehousing costs, and reduced training costs far outweigh the costs of developing an operational ES for HCC assignment.

C. Field testing of the HAZMACS prototype will be successful if it can be demonstrated that DLA depot personnel appreciate the importance of accurate assignment of HCCs and are convinced of the advantages that a system like HAZMACS offers over other alternatives.

D. Because of the size and complexity of HAZMACS, the personal computer based application package used for this prototype may not be appropriate for an operational ES. Accordingly, it may be prudent to consider employing other resources (i.e., software, hardware, personnel) to develop an operational system.

III. RECOMMENDATIONS

A. DLA-OW should proceed with field testing of the HAZMACS prototype. Testing should be performed at all three DLA hazardous material depots (i.e., Defense Depot Richmond, Defense Depot Memphis, Defense Depot Ogden).

B. Subject to successful field testing of the HAZMACS prototype, DLA-OW should proceed with development of an operational expert system. It may be appropriate, however, to utilize resources (i.e., software, hardware, personnel) other than those used to develop the prototype.

IV. BENEFITS. Development of the HAZMACS prototype has enabled a better informed decision to be made regarding the suitability of employing AI/ES technology in implementing the new Hazardous Characteristic Coding System. If a decision is made not to proceed with development of an operational system, the only cost to DLA is the relatively small investment in personnel and computer resources used to develop the prototype system. However, if an operational version of the HAZMACS is developed, it is believed that the benefits (and cost avoidances) to be derived would include the following:

- accurate identification of hazardous materials leading to improved accuracy in selecting storage locations and reduced re-warehousing costs.

- better identification of hazardous materials resulting in safer storage and handling of materials and fewer accidents, spills, etc.

- avoidance of training costs that would otherwise be required to develop and maintain "human experts" at the various DLA depots.

V. IMPLEMENTATION

On 14 March 1989 the completed HAZMACS prototype was delivered to DLA-OW. Field testing of HAZMACS will be supervised by DLA-OW and will probably begin at Defense Depot Richmond (DDRV). It is anticipated that DORO will provide technical assistance during the field testing phase and, to that end, the Appendix to this report provides instructions on "How to Use HAZMACS."

Assuming that, after completion of field testing, it is deemed to be feasible and advisable to expand HAZMACS into an operational system, two additional issues will need to be resolved. The first issue is whether the operational system should be PC-based. The HAZMACS prototype was developed on a Zenith 248 personal computer and will run on an IBM PC, AT or XT. However, the prototype has more than 400 rules and, with its associated programs, takes up almost all available space on a single floppy disk. An operational version of HAZMACS could have as many as 2000 rules and will require two floppy disks. It is possible, therefore, that a large PC-based system may not be advisable due to storage space constraints or unacceptable response times. Accordingly, it may be prudent to consider alternative software and/or hardware for developing the operational system.

Related to this issue is the question of who should develop the operational expert system. Although DORO's role in AI/ES application development is normally limited to prototyping, the development of complete PC-based systems is within our capabilities. However, if it is determined that a PC-based system is not appropriate or that the M1 software package should not be used, it may be necessary to employ other resources to develop the operational expert system or incur delays in development while DORO acquires more suitable hardware, software and development skills.

VI. METHODOLOGY. HAZMACS is a PC-based ES which queries the user about the known characteristics of suspected hazardous material and assigns, if possible, an HCC based upon the user's responses. The general approach used in developing HAZMACS consisted of building a hazardous material knowledge base, converting that knowledge base into an ES application rule base, and testing of the rule base by experienced chemists/engineers at various stages during the evolution of the prototype.

A. Knowledge Base Development. Between July and October 1988, several interviews were conducted with the Chief of DGSC-SLM and a chemical engineer on his staff. As DLA's experts in the domain of hazardous materials analysis and classification, these individuals were the logical choices to serve as the "domain experts" for this project. These interviews, or knowledge acquisition sessions, enabled the project analyst to obtain a general understanding of the hazardous material domain and associated terminology and to become familiar with the HMIS. Additionally, the process by which information is extracted, analyzed, and encoded into the HMIS was examined in detail. Pertinent manuals, handbooks, regulations, and other documentation were obtained and reviewed. At the request of the project analyst, the domain experts provided several annotated copies of typical documentation (e.g., Material Safety Data Sheets, HMIS data sheets) now used in analyzing and classifying items to be added to the HMIS. Additionally, the project analyst visited a hazardous material warehouse at DDRV to obtain first-hand knowledge of the labels, placards, shipping papers, and other indicators which may accompany hazardous material shipments to DLA depots.

B. Application Rule Base Development

The hazardous material knowledge base which was acquired in the manner described above was converted to an application rule base using the M1 ES software package developed by TeKnowledge, Inc. M1 uses a premise-conclusion or "if-then" approach to knowledge representation. For example, the fact that an acid has a pH of 4.0 or less might be represented in M1 as follows:

```
Rule - 01:  if pH = 4.0 or less
            then acid - indicated.
```

M1 primarily uses what is known as a "backward chaining" approach to evaluation of the application rule base. This means that M1 will search the rule base for a conclusion which solves the present problem or answers the current question. Once a rule is found which draws such a conclusion, M1 will than test the premise(s) of this rule to determine if, in fact, the desired conclusion is true. In our example, the conclusion "acid - indicated" would only be true if the premise "ph = 4.0 or less" were found to be true.

C. Rule Base Testing. Between 22 November 1988 and 19 January 1989, three successive versions of HAZMACS were created and shared with DGSC-SLM and DLA-OW. This approach was taken in order to provide ample opportunity for the domain experts and the client to thoroughly evaluate the prototype. Accordingly, the project analyst obtained valuable feedback not only regarding the technical accuracy of the rule base but also with respect to the "user friendliness" of HAZMACS. Specifically, this feedback led to major improvements to the prototype in terms of:

- the types of questions asked and the logical ordering of those questions.

- the capability of HAZMACS to explain why it is asking specific questions and to suggest possible sources of information.

- the ability of HAZMACS to test for inconsistent user responses.

VII. ANALYSIS

A. Feasibililty of an AI/ES Solution. It was stated previously that the feasibility of employing AI/ES technology in the assignment of HCCs would be demonstrated by a prototype system which exhibited the following characteristics:

- the ability to accurately and quickly assign HCCs.

- the capacity to obtain necessary information with minimum interaction by the user.

- the flexibility to either identify a general hazardous category for storage purposes or determine the specific HCC for entry into the HMIS.

Throughout its development, HAZMACS was subjected to rigorous testing and validation by the client and the domain experts at various stages during the evolution of the prototype. As a result, HAZMACS now has the capability to accurately assign ten HCCs encompassing corrosive material, selected flammable material and some items manifesting multiple hazards. In conjunction with assigning an HCC, HAZMACS explains the rationale for that assignment. This feature provides a significant degree of quality control on HAZMACS decisions, especially in the event the user makes a data entry error.

Although the prototype must obtain all of its input information from the user, all HAZMACS queries allow the user to either select from a menu of optional answers or simply respond yes or no. Typically, the experienced user should be able to obtain an HCC assignment from HAZMACS in two minutes or less.

In the course of developing the prototype, it was decided that HAZMACS should always attempt to assign an HCC. Only in those cases where the HCC cannot be determined from available information will HAZMACS try to identify a general hazard class (e.g., Corrosive, Flammable, Oxidizer, etc.). This approach was taken due to the fact that, under DWASP, the HCC will be needed in order for a specific storage location to be assigned.

HAZMACS will not always be able to give the user an answer. If insufficient information is known about an item or if the user's responses to queries are inconsistent (e.g., a DOT class of Corrosive and a UN Class of Flammable Liquid), HAZMACS will display a message to that effect.

B. Advisability of an AI/ES Solution

During early discussions on this project, DLA-SC expressed some concern that the development of an expert system for classifying hazardous materials would require an inordinate amount of time from the domain experts located at DGSC-SLM. DLA-SC was concerned that involvement in this project could detract from DGSC-SLM's primary responsibility of maintaining the HMIS. It is true that during the very early stages of knowledge acquisition, several lengthy interviews with DGSC-SLM were required. Since November 1988, however, the involvement of DGSC-SLM has been essentially confined to evaluation of several interim versions of the prototype. In all cases, the domain experts were given a minimum of two calendar weeks for their evaluations and, to our knowledge, these evaluations did not place unacceptable demands on the personnel involved. If HAZMACS were to be expanded to an operational system, it is anticipated that a similar process of testing and validating a series of interim systems could be employed effectively. It is also believed that the potential benefits to be derived from an operational expert system far outweigh the costs of its development. Those benefits (and cost avoidances) which pertain to reduced re-warehousing costs, safer storage and handling, and reduced training costs were previously described in detail in section IV of this report.

Another important factor to be considered before proceeding to develop an operational expert system is how receptive the end-users are to the HAZMACS prototype. Realistically, it may be difficult for depot receiving personnel to appreciate the capabilities of HAZMACS. This is because these personnel are not now responsible for assignment of hazard codes. As field testing of the HAZMACS prototype is implemented, it will be incumbent upon DLA-OW to convince depot personnel of the importance of accurate implementation of the new hazard coding system and the advantages that a system like HAZMACS offers over other alternatives.

APPENDIX A

How to Use HAZMACS

I. INTRODUCTION

The Hazardous Material Analysis and Coding System (HAZMACS) is a prototype expert system which assigns Hazardous Characteristic Codes (HCCs) to a selected category of hazardous materials. It is intended for use by depot receiving personnel who, under the new DLA Warehousing and Shipping Procedures (DWASP), will be required to assign the HCC if it is missing from pertinent documents.

Currently HAZMACS can assign the following HCCs:

HCC		Hazard Code
C1	-	Corrosive, DOT, Acid
C2	-	Corrosive, DOT, Alkali
C3	-	Acid, Low Risk
C4	-	Alkali, Low Risk
D4	-	Oxidizer and Corrosive
F6	-	Flammable Liquid and Corrosive
F7	-	Flammable Solid
J1	-	Miscellaneous Flammable Liquid
J2	-	Miscellaneous Flammable Solid
J6	-	Miscellaneous Corrosive Material

II. INPUT REQUIREMENTS

HAZMACS is a PC-based expert system which asks the user a series of questions about the known characteristics of suspected hazardous material and assigns, if possible, an HCC based upon the user's responses. Although this prototype system must obtain all of its input information from the user, all of the questions which HAZMACS asks can be answered by either selecting from a menu of optional answers or simply responding yes or no. With a little practice, the user should be able to obtain an HCC assignment from HAZMACS in two minutes or less.

The questions which HAZMACS asks are based on the assumption that one or more of the following sources of information are available to the user:

Material Safety Data Sheet (MSDS)

Shipping Papers

DOT Shipping Labels

Markings or Indicators

In addition, the user can obtain clarification of any question as well as suggested sources of information by pressing the F8 key.

III. EXECUTION PROCEDURES

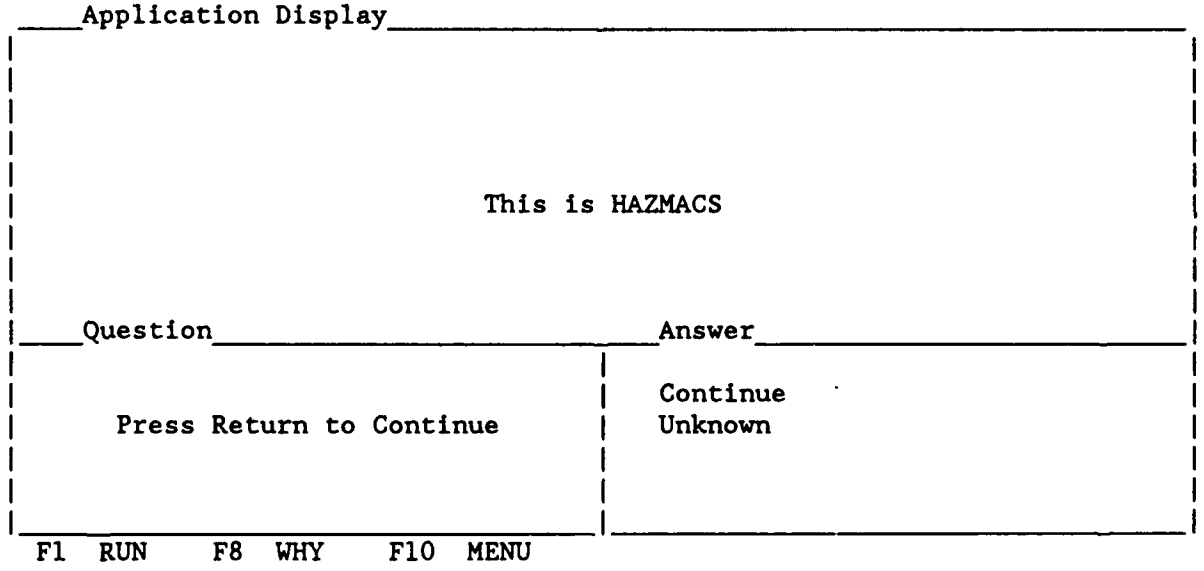
The following step by step instructions are based on the sample problem described below:

Sample Problem

A shipment of suspected hazardous material has arrived at Depot X. Based on the shipping papers and Material Safety Data Sheet which accompanied this shipment, the following information is known:

Product Name:	XYZ Boiler Cleaning Solution
Chemical Name:	Morpholine
UN Class:	3
pH:	13.1
Flash Point:	95 degrees F (c.c)
Materials to Avoid:	ACIDS
Quantity Shipped:	100 containers of 10 gallons each

HAZMACS Screen	Instructions
-	- Place the HAZMACS diskette into drive A.
-	- At the "A" prompt on your PC screen, type "go" and press return.
-	- Wait while the system is loading (approximately 25 seconds on a Zenith 248).
Screen 1	- After HAZMACS is loaded, the first screen will appear. Each HAZMACS screen is divided into an "Application Display" area, a "Question" area and an "Answer" area as shown below:



HAZMACS Screen	Instructions
Screen 1	- You may display available menu options by pressing the F10 key. Available options are: abort consultation - F3 exit to DOS - F4 go run consultation - F1 restart consultation - F5 why is HAZMACS asking - F8
Screen 1	- Press the return (enter) key to continue.
Screen 2	- The next screen explains that you will be asked a series of questions and that <u>you can obtain additional information by pressing the F8 key</u>.
Screen 2	- Press return to continue.
Screen 3	- You are now asked to select the DOT Hazard Class. Since, in our sample problem, the DOT Hazard Class is unknown, press the "down" arrow key to scroll to the end of the optional answer list. Press return. (<u>Hint</u>: You may also scroll to end immediately by pressing the "up" arrow key.)
Screen 4	- Since we do know the UN Hazard Class, select "yes" and press return.
Screen 5	- Using the "down" arrow key, scroll to "Class 3." Press return.
Screen 6	- Since we do not know the shipping name, press the "down" arrow key to scroll to the end of the answer list. Press return.
Screen 7	- Using the "down" arrow key, scroll through the optional answers to see if any terms are listed which also appear in this material's product name or chemical name. Since none are listed in our sample case, select "Other" or "Unknown." Press return.
Screen 8	- Since we do know that acids should not be brought into contact with this material, select "Acids." Press return.
Screen 9	- Since we know the pH, select "yes." Press return.
Screen 10	- Since the pH for this material is 13.1, scroll down and select "12.5 or more." Press return.

HAZMACS Screen	Instructions
Screen 11	- Since the quantity shipped was 100 containers of 10 gallons each, select "no." Press return.
Screen 12	- Since we know that the UN Hazard Class for this material is "Flammable Liquid", select "yes." Press return.
Screen 13	- Since the UN Class is "Flammable Liquid", select "Flammable." Press Return.
Screen 14	- Since the flash point is known, select "yes." Press return.
Screen 15	- Since the flash point for this material is 95 degrees F (c.c.), select "141 degrees F (c.c.) or less." Press return.
Screen 16	- Since the product name indicates that this material is a "solution", select "LIQUID." Press return.
Screen 17	- HAZMACS assigns an HCC and displays the following message: HAZMACS assigns an HCC of: F6 FLAMMABLE LIQUID AND CORROSIVE because - * This material carries a UN Classification of FLAMMABLE LIQUID * The item's pH is in the ALKALINE range of 12.5 or more * The Flash Point is in the FLAMMABLE range of: 141 deg F (c.c) or less * Materials to avoid bringing into contact with this item are: ACIDS * The material is a LIQUID

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**************************************************************************
*                      This Consultation is over.                        *
*         Press F1 if you would like to begin a new consultation.        *
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- - Press F1 to begin a new consultation.

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The emerging technology of Artificial Intelligence/Expert Systems (AI/ES) offers the potential to automate tasks which now require human judgment, experience and intuition. Because implementing this technology can be expensive, especially if done inappropriately, the Defense Logistics Agency Operations Research and Economic Analysis Management Support Office (DORO) has chosen to develop prototype systems in order to determine the suitability of AI/ES solutions to specific logistics problems. This report documents the development of a prototype expert system designed to demonstrate the feasibility of using AI to support the implementation of a new hazardous material classification system.

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